Performance Analysis of a Two-Shaft Gas Turbine Engine

AE 451A - Experiments in Aerospace Engineering-III

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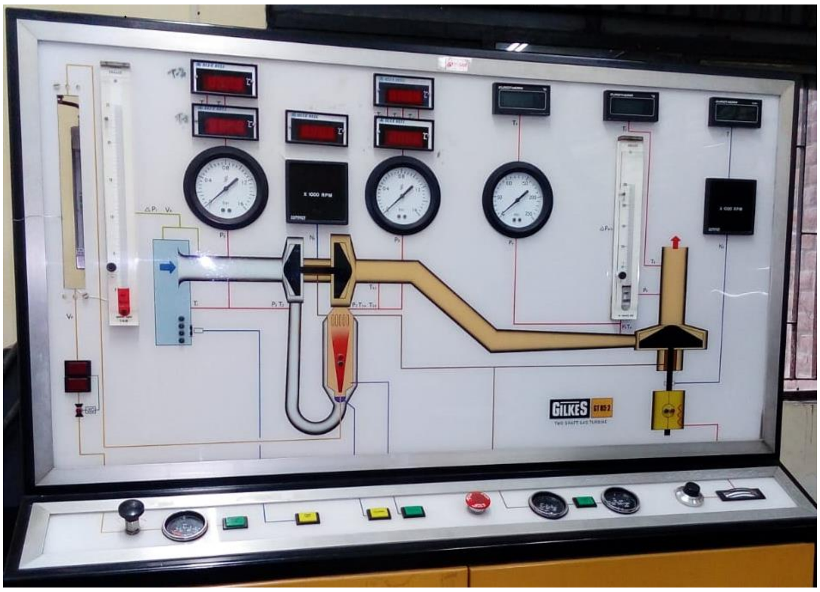


Figure 1. Two shaft gas turbine engine set-up.

LIST OF SYMBOLS:

Symbol	Meaning	SI Units
C_p	Specific heat at constant pressure	J/(kg-K)
m_a	Air mass flow rate	kg/s
m_f	Fuel mass flow rate	kg/s
ρ	Density	kg/m^3

Symbol	Meaning	SI Units
P_0	Total pressure	Pa
T_0	Total temperature	K
T	Static temperature	K
γ	Ratio of specific heats	-

OBJECTIVE:

The objective is to understand the operation and evaluate the performance of a power generating gas turbine engine, and obtain the component efficiencies.

DESCRIPTION OF EXPERIMENT:

To investigate the performance of a gas turbine, a two-shaft turbocharger based gas turbine engine set-up, GT85-2, Gilbert, Gike & Gordan Ltd. England is used, see Fig. 1. The engine includes three processes, namely, compression, combustion and expansion.

The compression is carried out by a single stage centrifugal compressor operating at speeds upto 90,000 rpm with pressure ratio upto 2.2. The compressor is driven by a single stage turbine whose only function is to provide power to the compressor.

The discharge from the compressor is fed to the combustion chamber where it is used to burn aviation turbine fuel (ATF) with stoichiometric air/fuel ratio of approximately 15:1.

The combustion products at the combustor exit, at temperatures upto 700 ˚C are fed to the single stage turbine powering the compressor and then to the single stage power turbine (to generate mechanical power which is absorbed by the load dynamometer). The net power output of the gas turbine set-up goes upto 7 kW.

The discharge from the power turbine is then exhausted to the atmosphere.

CHECKLIST BEFORE STARTING:

1. Check that the water supply is ON for cooling purpose.
2. Check that the oil supply pressure and temperature is appropriate.
3. Make sure there is sufficient fuel for a complete test run.

PROCEDURE:

1. Before starting the experiment, familiarize yourself with various components of the test set-up as well as the instrument panel.
2. Learn the starting procedure and operation of the test set with the help of “Technical Handbook” provided by the manufacturer and the Laboratory staff. Do not operate the test set-up in the absence of a lab staff member.
3. Turn ON the main switch and after that Turn ON the water supply and oil supply switch.
4. Start only one electric fan. When fan has started, inject alcohol into the combustion chamber and turn ON the spark plug. Hold the alcohol injection and spark plug switch in ON position until combustion chamber temperature reaches above 100˚C. Once the combustion chamber temperature reachees above 100˚C release the switch (Turn OFF).
5. When the 1st turbine speed is approximately equal to 50,000 rpm, turn OFF the electric fan and start the experiment.
6. Note down the readings at different rpms.
7. The operational speed range of the gas turbine set-up is given below and must not be exceeded.

Gas Generator speed: $50,000 < N1 < 90,000$ rpm.

Power turbine speed: $5,000 < N2 < 40,000$ rpm.

OBSERVATIONS/MEASUREMENTS:

1. One the set-up is running steadily at a particular rpm, record the values of all the variables such as pressure, temperature, etc. readable from the instrument panel at different sections of the gas turbine.

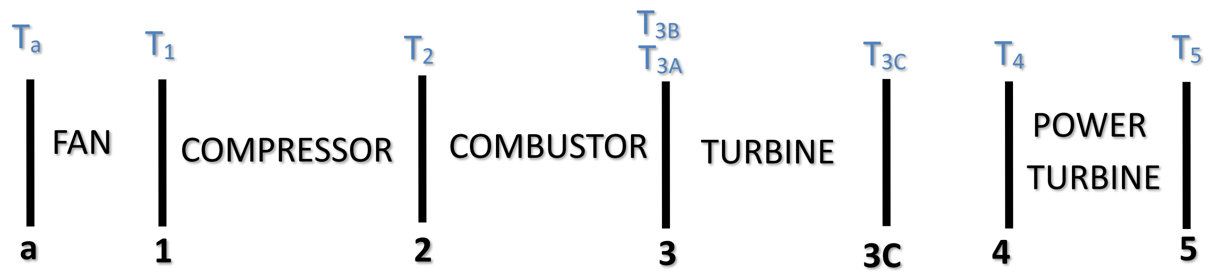
Note that all the pressure and temperature measurements are static values and are assumed to be equal to the total values as the Mach number is low for the present case.

PRECAUTIONS:

1. Do not operate unless a lab technician or teaching assistant is present.
2. NEVER exceed the maximum fuel flow rate limit of 12 LPH.
3. While increasing the fuel supply, do so slowly, in the stipulated increments only.
4. Keep in mind the maximum power turbine speed is 40,000 rpm, if it exceeds 40,000 rpm give the load by using load dynamometer.
5. During the experiment, the gas turbine components will get very hot. Do not touch any part of the gas turbine during the experiment.
6. Stay well away from the exhaust of the gas turbine during operation.

CALCULATION PROCEDURE:

Block diagram with station numbering and blank data set for calculations.



Station Number	a	1	2	3	3C	4	5
Pressure (bar)							
Temperature (^oC)							
Air mass flow rate (kg/s)							
Fuel flow rate (LPH)							

Station a - Ambient conditions and fan inlet

Station 1 - Fan exit and compressor inlet

Station 2 - Compressor exit and combustor inlet

Station 3 - Combustor exit and turbine inlet

Station 3C - Turbine exit

Station 4 - Power turbine inlet

Station 5 - Power turbine exit

[Note down the Pressure, Temperature and Air mass flow rate at different stations at different fuel flow rates metered using a rotameter, choose 4-5 fuel flow rates between 5 to 10 LPH]

1. Units Conversion and other assumptions:

$$m_a\left(\frac{kg}{s}\right) = \frac{0.9597\times\sqrt{\Delta P}\times\sqrt{P_1}}{\sqrt{T_1}}$$

$$m_f\left(\frac{kg}{s}\right) = \frac{m_f(LPH)\times\rho_{fuel}}{3600\times1000}$$

Where, $\rho_{fuel} = 840\ \frac{kg}{m^3}\ and$

ΔP is pressure difference across the fan.

T_1 is in Kelvin.

P_1 is in bar and ΔP is in mbar.

$\gamma_{cold} = 1.4$ and $\gamma_{hot} = 1.33$

$C_P(cold) = 1005\ (\frac{J}{kg.K})\ and\ C_P(hot) = 1150\ (\frac{J}{kg.K})$

2. Ambient Conditions:

Pressure (P_{amb}) = measured from barometer in lab or assume 1.01 bar

Temperature (T_{amb}) = measured from thermometer in lab

8. Compressor Inlet Pressure:

$P_1 = P_{amb} + \Delta P$

9. Compressor Pressure Ratio (P_2/P_1):

Since the measured value is gauge pressure, we add ambient pressure to get the absolute pressure.

10. Compressor Efficiency:

$$\eta_c = \left(\frac{\left(\frac{P_2}{P_1}\right)^{\frac{\gamma_{cold}-1}{\gamma_{cold}}} - 1}{\frac{T_2}{T_1} - 1} \right)$$

11. Turbine Efficiency:

$$\eta_t = \left(\frac{1 - \frac{T_{3C}}{T_3}}{1 - \left(\frac{P_{3C}}{P_3}\right)^{\frac{\gamma_{hot}-1}{\gamma_{hot}}}} \right)$$

12. Power Turbine Exit Pressure:

$P_5 = P_4 - \Delta P_{45}$

ΔP_{45} is pressure drop in the power turbine (entry – exit)

13. Global Equivalence Ratio:

$$\Phi = \frac{(A/F)_{\text{Stoich}}}{(A/F)}$$

Air/Fuel ratio is $(\frac{A}{F} = \frac{m_a}{m_f})$ and Stoichiometric Air to Fuel ratio can be calculated using the stoichiometric equation for the combustion of ATF (use $C_{12}H_{26}$ to simulate ATF composition)

14. Power:

$$Net\ power = (m_a + m_f) \times C_P(hot) \times (T_4 - T_5)$$

Overall Efficiency:

$$\eta_{\boldsymbol{o}} = \left(\frac{(m_{\mathrm{a}}+m_f)\times C_P(hot)\times(T_4-T_5)}{m_f\times Q(LCV)}\right)$$

Assume lower calorific value for ATF [Q(LCV)] is 44.5 MJ/kg.

RESULTS AND DISCUSSION:

1. Record in a tabulated form the computed results for different fuel flow rates (choose 4-5 fuel flow rates between 5 to 10 LPH).
2. Discuss the behaviour of the observed and calculated data obtained for this gas turbine in the light of the general characteristics of the gas turbine engine learnt by you in courses.
3. Plot all the measured efficiencies with fuel flow rate and discuss the trends.

REFERENCES

[1] Cohen H, Rogers G, Saravanamuttoo H. Gas Turbine Theory. Fourth Edition. 1996.

[2] Walsh P, Fletcher P. Gas Turbine Performance. Second Edition. 2004.